Journal of Physics Special Topics

P4_4 The Solar Cell Efficiency of Superman

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October 31, 2013

Abstract
The paper investigates how efficiently Superman must absorb energy from the Sun's emission spectrum to be able to perform flight for 8 hours at a constant altitude. A solar cell efficiency of 656000% is calculated, which seemingly disobeys the law of conservation of energy assuming the model of Superman as a solar cell is reasonable.

Introduction

Superman is one of the most well-known comic book characters created. Since being published by DC comics in 1933, there have been many changes made to the concept of this character. One interesting development pertains to the source of Superman's power. Originally, his powers were a result of the evolution of his species [1]. In the 1940s the source was changed to be a combination of the lower gravity on Earth compared to Krypton, and the light of our "yellow sun" [2]. It was stated that Kryptonians possessed no powers on Krypton because of the planet's orbit around a red star, named Rao.

Through treatment of Superman as a solar cell, in which he absorbs all the energy from the electromagnetic radiation of the Sun, this paper will find his solar cell efficiency. To achieve this, the absorbed energy will be compared to an estimate of Superman's energy usage through consideration of one of his more quantifiable powers – the ability of flight.

Theory

Although the concept of a "yellow sun" is a misnomer, (the Sun is actually white in absence of the Rayleigh scattering in the atmosphere) the idea that Superman could get additional energy from our Sun compared to a red star, thus enabling his extra-ordinary abilities, is conceivable. To confirm its conceivability, we can look at the spectral radiance of the Sun through its treatment as a blackbody [3], which involves the use of the Planck function. This function describes the spectral radiance as a function of wavelength for a particular temperature as illustrated by Figure 1.

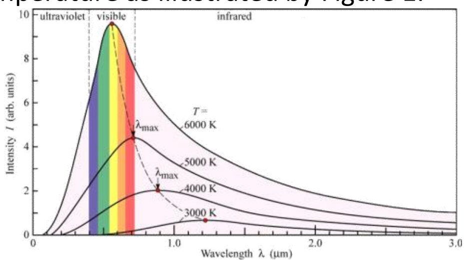

Figure 1 - The Planck function for various temperatures. [4]

Through Figure 1, it is observed that a lower temperature results in a lower total radiance, and a peak at a lower wavelength. This is quantified by Wien's displacement law [5],

$$\lambda_{max}T = 2.898 \times 10^{-3}\,, \qquad \text{(Eq. 1)}$$

where λ_{max} is the wavelength in meters, and T is the temperature in Kelvin. Therefore by considering the Sun and Rao as blackbodies, it can be stated that the red star Rao is a lower temperature star compared with the Sun, thereby emitting a lower total radiance.

Energy absorbed from the Sun

To calculate the energy Superman absorbs from the Sun it will be assumed that he is susceptible to the entire spectrum of radiation and flies at an altitude of 30,000 m. The density of air at this altitude is 1.5% of the value at sea level [6]. This severely reduces the impact of atmospheric absorption on the Sun's emission spectrum. The solar irradiance per unit area is therefore the solar constant, S_C = 1.37 kW/m^2 [5]. When flying around Earth, the irradiance is incident on an area A_{SB} defined by Superman's back profile, assuming that his costume does not impede his energy absorption. Using the height of 1.75 m and shoulder width of 0.457 m [7] for an average male, a rectangle of area 0.8 m^2 can be used to approximate A_{SB}. Consequently Superman absorbs 1096 Js^{-1} from the Sun.

Energy used when flying

While remaining at a constant altitude the work done by Superman is a combination of the energy required to change velocity, and the work done against drag forces. The equation defining the drag force F_D is [8]

$$F_D = \frac{1}{2} C_D \rho v^2 A \,, \qquad \text{(Eq. 2)}$$

where ρ is the air density, A is the orthographic projection of superman's body from above his head, and v = 1000 ms^{-1} is the velocity of Superman generically chosen for this calculation. C_D is the drag coefficient, which quantifies how aerodynamic an object is. It is possible to find C_D from the terminal velocity v_T, where F_D equals the force due to gravity;

$$C_D = \frac{2 m_s g}{\rho v_T^2 A} \,, \qquad \text{(Eq. 3)}$$

where m_S = 102 kg [1] is the mass of superman, and g = 9.81 ms^{-2} is the acceleration due to gravity. A value for v_T can be obtained from Felix Baumgartner's record breaking skydive in which he reached a value of v_T = 373 ms^{-1} at an altitude of approximately 30,000 m [9]. Combining equations 2 and 3 expresses the drag force in terms of the terminal velocity and the final velocity. If this new equation is also combined with $\frac{W_D}{t} = F_D . v$ where t = 8 hours is the duration of flight, an equation of the work done W_D against drag forces is obtained. Finally, to get W_T, the total work done by Superman during flight, the work done against drag forces must be summed with the change in kinetic energy:

$$W_T = \frac{1}{2} m_S (v^2 - v_0^2) + m_S g \frac{v^3}{v_T^2} t, \qquad \text{(Eq. 4)}$$

where v_0 is the initial velocity which is taken to be 0. The change in kinetic energy is assumed to be instantaneous, so as to reduce the impact of drag forces in this stage. Inputting the values stated through this paper result in a value of W_T = 2.07×10^{11} J.

Efficiency

With the values of absorbed energy and consumed energy it is now possible to obtain a value for the solar cell efficiency η using [3]

$$\eta = \frac{W_T}{S_C A_{SB} t} \,, \qquad \text{(Eq. 5)}$$

producing an efficiency of 656000%.

Conclusion

The result of 656000% for the efficiency of Superman as a solar cell is incomparable to anything on the planet Earth - the highest efficiency so far achieved is 44.7% [10]. This result seemingly disobeys the law of conservation of energy; he is using more energy than he obtains. Alternatively, Superman must be obtaining energy in addition to the electromagnetic radiation from the Sun. It is also possible that instead of immediately using all energy he obtains, he stores the energy for future use. However even with a solar cell efficiency of 100% Superman would soon reach a depletion of energy, especially when the calculation in this paper only considers one of his many super-human abilities.

References

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